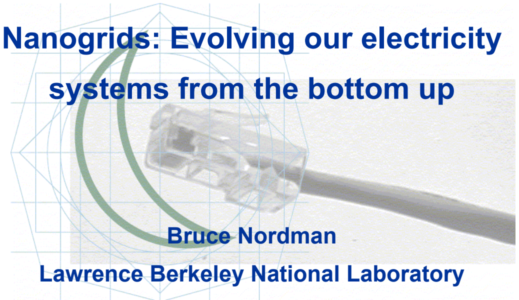
Darnell Green Building Power Forum

Nanogrids: Evolving our electricity systems from the bottom up



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Overview

- What is a Nanogrid?
- Relation to other grids
- Examples
- Implementation
- The way forward

This an initial proposal, not a final design

Examples

No communications

- Vehicles – 12 V, 42 V, …
- eMerge – 24 V, 380 V
- Downstream of UPS – 115 VAC

With communications

- Universal Serial Bus, USB – 5 V
- Power over Ethernet, PoE – 48 V
- Proprietary systems

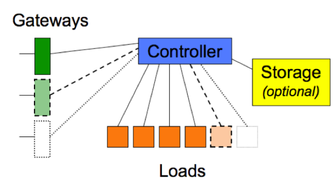
Power adapter systems

- Universal Power Adapter for Mobile Devices, UPAMD – IEEE
- Greenplug, Inc.
- Wireless technologies

What is a Nanogrid?

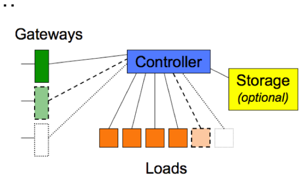
"A (very) small electricity domain"

- Like a microgrid, only (much) smaller
- Has a single physical layer (voltage; usually DC)
- May have control
- Is a single administrative, reliability, and price domain
- Can interoperate with other (nano, micro) grids through gateways



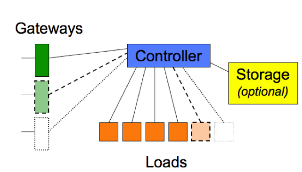
Nanogrid details

- Must have at least one load*
- Must have a gateway*
  - Can be intermittently connected
  - Supply always via a gateway
- **Only implement power distribution**
  - **Devices control themselves for functionality**
- Can be highly dynamic in connected devices, power flow quantity (and direction), …
- Range in functionality of controls, gateways
- Loads usually < 100 W, sometimes < 1 W



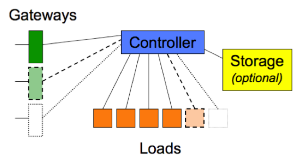
Controller

- Can have ability to grant or revoke power to loads
- Negotiates with other grids through gateways
- Sets prices
- Manages storage
- Is **the** authority within the grid
- (Should) Provide minimal power to loads at all times to maintain communications ability
- Deals with loads that do not communicate



Gateways

- Can be one-way or two-way (for power)
- Most functional when communications exist
- Can be to a nanogrid, microgrid, or the megagrid
- Have a capacity limit
- Exchange voltage: ???
- Only information that passes across gateway is price, capacity, and availability
- Perhaps storage is just a (special) gateway?



Price

- Not required — but really useful
- Basic mechanism for devices to express preferences
- Can be unitary or a time series forecast
- Is local only to the nanogrid
- Used in deciding when to
  - exchange power across gateways
  - add to or withdraw from storage
- Exchange losses dictate differential ‘buying’ and ‘selling’ prices (gateway and storage)
- Gateways *may* track energy flows and prices

Relation to other grids

- Macrogrid (megagrid)
  - Large
  - No direct coordination between sources and loads
  - Oversizing and diversity enable this
- As grids get smaller
  - Potential for supply/demand imbalances increase
  - Need for coordination grows
  - Off-grid operation requires local generation or storage
  - Advances in communications technology enables coordination not before possible

Micrograms

- better integrate local (distributed) generation
- optimize multiple-output energy systems (e.g. combined heat and power, CHP)
- better integrate local storage
- provide a variety of voltages, including DC
- provide a variety of quality and reliability options.
- operate independently of the macrogrid (or connected)
- hide microgrid details from the macrogrid

Nanogrids implement only some of these

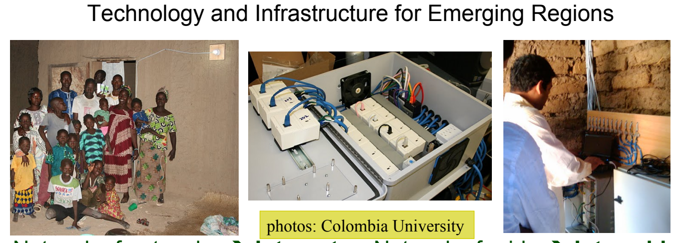
Microgrids vs. Nanogrids

• Few	• Many
• Building/campus scale	• Few connected devices
• Multiple voltage, reliability domains	• Single voltage, reliability domain
• Includes generation	• No generation
• Have to deal with implementation issues	• Already works!

- *Bottom-up approaches are more deployable, flexible, cost-effective, functional*
- *Nanogrids can enable a “better grid” faster and cheaper than the “smart grid” (though they can co-exist)*

Inspiration

- Existing technology
- Modeling network architecture on Internet
  - Randy Katz et al., UCB; “LoCal” – local.cs.berkeley.edu
- Developing country needs; off-grid households
  - Eric Brewer, UCB; TIER – tier.cs.berkeley.edu Technology and Infrastructure for Emerging Regions



photos: Colombia University

Network of networks ➔ **Internet** — Network of grids ➔ **Intergrid**

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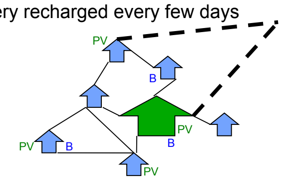
Implementation

- Will be used because they are convenient
- Enable easy sharing of (surplus) local generation
- May (or may not) have efficiency advantages
- Most NG connected to the macrogrid (intermittently)
  - Even vehicles will be
- Price mechanism ensures that all power exchanges are mutually beneficial
- Gateways have "friction" — this enhances stability
- Using same technologies in many domains ensures that they are cheap and available for very poor
  - Example: proliferation of mobile phones

Village example

- Start with single house – car battery recharged every few days
  - Light, phone charger, TV, ???
  - Add local generation – PV, wind, …
- Neighbors do same
  - Interconnect two houses
- School gets PV
  - More variable demand
- Eventually all houses, businesses connected in a mesh
  - Can consider when topology should be changed
- Existence of generation, storage, households, connections all dynamic
- Can later add grid connection



Communication

- Ideally use functional communication path for power coordination, e.g. USB, PoE
- Otherwise need simple, robust, slow physical layers
- Single physical layer for power coordination within a NG
- At gateways need standard communication
  - G.hn? Internet Zero?
  - Need single gateway protocol / physical layer
- All communication only requires data links
  - not (complicated) network infrastructure

The way forward

- Better document **existing** nanogrids
  - Capabilities, uses, …
- Define a "meta-architecture" for operation, gateways, prices
- Define specific gateways (voltage, communication)
- Define nanogrid implementation for existing technologies
- **Always** keep power distribution and functionality separate
- Identify promising applications
- Demonstrate, document, market
- Bring (more, better) nanogrids to the neediest
- Test price mechanism

Nanogrids and the Smart Grid

- Nanogrids can (are) implemented only locally
- Nanogrids provide obvious benefit to users
  - Ride on functional advantages for cost, motivation
  - Benefits are immediate
- Nanogrids enable easy evolution of technology, use
- Nanogrids can interoperate with a smart(er) grid
- Nanogrids are bottom-up and de-centralized
  - SG is top-down, centralized
- Smart Grid should end at the meter
- Smart Grid should use price/forecast dominantly
  - Only deviate when clearly needed / beneficial

Summary

- Nanogrids exist and are widespread
- They have many advantages
  - Likely better efficiency for native DC loads
  - Easier (cheaper) renewables integration
- Can help us quickly evolve our electricity system

Thank you